TURMOIL AT THE TOP OF THE WORLD

The Arctic's changing climate is literally turning the tundra upside down.

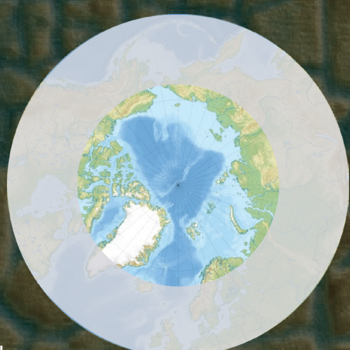
The texture of the summer tundra is bizarre when seen from above. It looks like crocodile skin: a watery expanse of patterned brown and green. This signature landscape is the result of complex interactions between soil and water at high latitude. But those interactions are being disrupted by a rapidly changing climate, and the pattern of the tundra is gradually being inverted—what once was low and wet is now high and dry, and vice versa. Recent work by Los Alamos geomorphologist Cathy Wilson, as part of a large multinational collaboration, has revealed that the changes are happening faster than previously appreciated.

"These findings are exciting but scary. I really hope this work helps the general public and policy makers understand just how vulnerable the Arctic is to climate change," says Wilson.

Not far beneath the surface, interspersed throughout the frozen soil are large vertical wedges of ice—the gradual product of water repeatedly trickling into crevices and then freezing. The ice wedges are conspicuous because the topsoil above them is raised into ridges (the result of water's expansion upon freezing). Ordinarily, these ridges abut one another, forming a network of meters-wide polygons with comparatively low centers, where ponds form in the summer and snow collects in the winter.

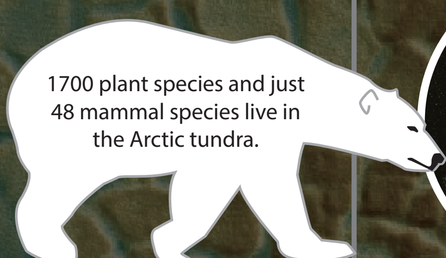
As the climate warms, the ice wedges, formed over hundreds of years, are melting from the top down. When the top of an ice wedge melts, the ridge of soil above it collapses into a trough, making the middle of the polygon comparatively higher, and causing the water from the central pond to drain into the trough. A tipping point arises when enough ridges collapse into troughs because they can connect to form a continuous network that drains these wetland landscapes. The Arctic tundra receives surprisingly little precipitation, so once that water is gone, it's gone. What used to be a stable and saturated system is transformed into something much drier and entirely new. Wilson and other Los Alamos scientists, along with external collaborators, are hustling to learn as much as they can so they might know what to expect in the future as warming continues.

About four million people in eight different countries live in the Arctic: the United States, Canada, Greenland (Denmark), Iceland, Norway, Sweden, Finland, and Russia.



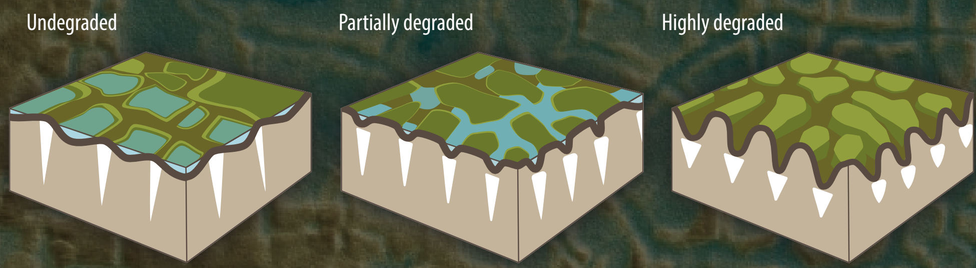
The Arctic tundra is one of the driest regions on Earth, with less than 10 inches of precipitation per year in most locations—less than the desert states of the American Southwest.

There is considerable variability in the Arctic climate, with winter temperatures occasionally dropping below -50°C (-58°F) and summer highs sometimes exceeding 30°C (86°F).



The oceans are 30% more acidic than they were when Mozart began composing at age four in 1760.

The Arctic ocean is acidifying twice as fast as other oceans.



Arctic warming is causing drastic changes to the tundra topography. (Left) In the undegraded state, low-centered, water-inundated polygons are surrounded by higher ridges that form above ice wedges. (Center) As ice wedges melt, the land above them collapses into troughs filled with water from the polygon ponds. (Right) In advanced degradation, the troughs become connected, forming a drainage network surrounding high-centered polygons.

It turns out that steadily rising average annual temperatures aren't the only concern. Even brief periods of unusual warmth, such as what's now regularly occurring in a single summer, can cause profound and irreversible ice-wedge degradation. The draining and drying of the tundra is worrisome because changing the hydrology of an ecosystem can change how essential elements, like carbon and nitrogen, cycle through—or out of—the system.

As the perpetually frozen soil, or permafrost, thaws, previously entombed plant material is made accessible to soil microbes that decompose the plants and release their elements into the environment as carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases. How will this process be affected by the draining of the polygon ponds? Will a drier landscape mean more CO_2 and less CH_4 emissions? How will increased drainage affect the kinds of plants that grow, and how will they, in turn, affect soil decomposition?

The team has seen major changes happen to most of its field sites in less than a decade. Through a combined approach of field observations, remote sensing, and hydrological modeling, Wilson and the others recorded extensive trough-network formation and considerable changes to water cycling that were linked to small changes in the tundra topography. Even a small amount of ground subsidence is consequential. Jeff Heikoop, a Los Alamos biogeochemist who collaborates with Wilson, emphasizes, "This work shows that when we say microtopography, we mean *really* micro. The ground sinking by less than a meter is enough to totally change the ecosystem."

Climate scientists predict that Arctic thawing will accelerate and spread. Many prognosticate a swampy future with the melting of ice wedges, permafrost, glaciers, and snowpack. But this work has shown that it's not as simple as warmer equals wetter. There are mechanisms, like the topographical inversion that Wilson studies, whereby warmer could equal drier. It's very complex and needs to be studied more. But regardless of warmer or wetter or lower or drier, the sixty-four-thousand-dollar question, the question on the minds of many climate scientists, goes back to the greenhouse gases: how much is being released and how fast? According to this study, the answer might well be "more and faster than we thought." LDRD

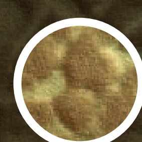
—Eleanor Hutterer

Arctic air temperature has increased by 5°C over the last 100 years.

Thawing permafrost is exposing a huge quantity of biomass, mostly dead plants, that has been frozen for eons. The decomposition of this biomass by microorganisms releases carbon into the atmosphere, further compounding warming and accelerating thaw.

Low-centered polygons

The melting of Arctic ice can contribute to rising sea levels and increased heat absorption by newly exposed soil, rock, and seawater.



High-centered polygons